X-ray Variability in M 87: 1992 – 1998

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Abstract. Beginning in 1995 June, we have obtained an observation of M 87 with the ROSAT High Resolution Imager (HRI) every 6 months. We present the measurements of X-ray intensity for the core and knot A through 1998 January. We find significant changes in both components. For the core, intensities measured in June 1995, December 1996, and December 1997 are roughly 30% higher than values obtained at three intervening times. For knot A, a secular decrease of approximately 15% is interrupted only by an intensity jump (3 σ) in December 1997. Because the background used for subtraction is probably underestimated, we suspect the actual variation is somewhat greater than these values indicate.

1 Introduction

The initial results of our X-ray monitoring of M 87 (Harris, Biretta, and Junor (1997), HBJ hereafter) were based on a re-analysis of two Einstein Observatory HRI observations, a ROSAT archival HRI pointing in June 1992, and the first two of our ongoing series of an observation every 6 months (June and December 1995). There we demonstrated that the core was variable at the 15% level and that knot A showed a gradual decline in intensity. In this paper we include data from 4 additional observations, with the most recent consisting of two segments: December 14, 1997 (8 ksec) and January 5, 1998 (20.6 ksec). We have also re-measured some of the earlier data to ensure that all data were treated uniformly.

2 Review of Problems and Measuring Techniques

There are three known problems affecting accurate photometry of ROSAT HRI data. The first is that the core and knot A (the two brightest features which we can measure with a 30 ksec observation) are separated by only 12″, thus precluding the use of the standard HRI aperture with r=10″. The second problem is that the central region of M 87 is X-ray bright with a

complex emission distribution (Harris, Biretta, and Junor (1998)), thereby making it difficult to estimate the surface brightness that would have been observed at the locations of the core and knot A if they were absent.

The most serious problem however, is the image degradation which means that the effective point response function (PRF) is widened and distorted from its quasi-Gaussian shape (FWHM $\approx 5.5''$) to an irregular distribution with FWHM of $7''$ to $10''$. The degradation is caused by bad aspect solutions; sometimes associated with the spacecraft wobble and occasionally to time segments for which the aspect solution can be up to $10''$ (or more) away from the primary solution. This situation means that we have no assurance that our standardized measuring areas contain the same fraction of total source counts for each observation.

To mitigate the severity of these problems, we made two separate measurements. For the first, we take the ratio of net counts in circular apertures ($r=6''$) centered on the core and knot A. To first order, we expect that the effective PRF will be the same for these close sources. Consequently the major error of this approach is that we will measure different fractions of the total source counts in different observations. Since the background correction uses a region with a slightly lower surface brightness than that found adjacent to the core and knot A, the non-variable background component will increasingly dilute any variable feature as the effective PRF gets larger; *i.e.* fewer photons from the unresolved component will remain within the small measuring aperture.

The second measurement utilizes two adjacent rectangles rotated by $20°$. Each rectangle is $16''$ by $26''$ with their common border ($26''$) perpendicular to the line joining the core and knot A, and centered on the 'reference point'. The reference point is halfway between the core and knot A. Surrounding these two rectangles is the background 'frame' which is $10''$ wide. This background frame is used both for the circular and rectangular measurements. The geometry is depicted in Fig. 2 of HBJ. The larger area of the rectangle compared to the small circle is designed to include most of the source counts even when there is substantial degradation of the PRF. However, since it will include more of the non-variable background, the actual variability should be somewhat greater than that found by this technique.

As a control, we also measure the net counts in a circular aperture ($r=12''$) centered $45''$ to the SE of the reference point (PA=$110°$). This location is on a plateau in the X-ray brightness distribution. Since we use the same background frame as for the other measurements, the resulting value is always negative.

Finally, to accommodate any changes in quantum efficiency we employed a 'self-calibration' by measuring the count rate of the bright part of the cluster gas within a large circle with radius $276''$, but excluding the adjacent rectangles containing the core and knot A. For this measurement, we used a background annulus with radii of $280''$ and $300''$. All measured net count

rates were then multiplied by a correction factor (always 5% or less) so that the cluster gas net count rate would be the same as that for our 'fiducial' observation of June 1995.
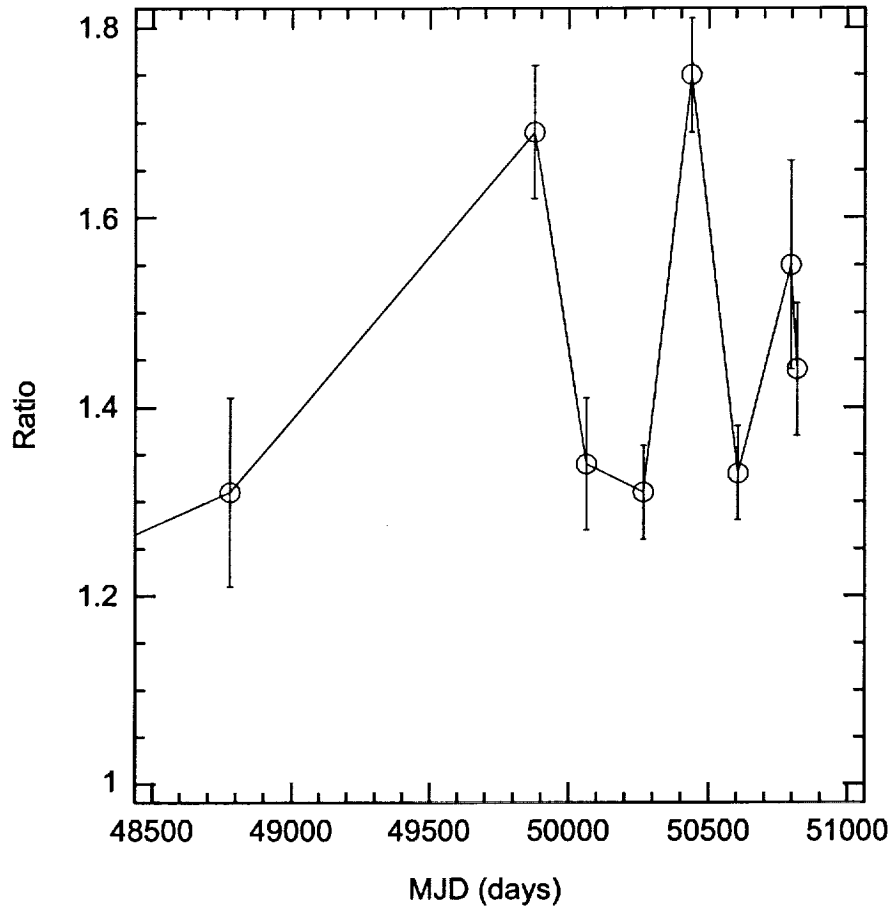
Fig. 1. The ratio of the core to knot A. Values are the ratio of net counts as measured in circular apertures with radius of 6″.

3 Results

The measured values are shown in Fig. 1 (the ratios) and 2 (the count rates). It can be seen that the major features of the ratio plot mimic the count rate variability for the core. This is consistent with expectations that the core

will be more variable than knot A. The decrease in the intensity of the core following the observation of June 1995 (MJD = 49876) coincides with the decrease observed with the HST between MJD 49840 and MJD 49921 (see Fig. 3 of Tsvetanov et al. (1998)).

In Biretta, Stern, and Harris (1991), we analyzed the Einstein HRI data and argued that the X-ray emission from knot A was most likely synchrotron emission rather than thermal bremsstrahlung or inverse Compton emission. For a magnetic field strength of $\approx 200\ \mu$G (the minimum pressure field), we found that electrons with Lorentz energy factors, γ, of 2×10^7 were required and typical half lives were of order ten years. The observed decrease of knot A (Fig. 2) is consistent with these estimates, but we do not yet understand why only a small fraction of shocks produce enough $\gamma = 10^7$ electrons to generate an X-ray intensity detectable with current technology. We suspect that even the knot A shock (≈ 70 pc across as measured at radio and optical wavelengths) is not a uniform single entity, but may well display a complex brightness distribution at the highest energies where synchrotron losses are severe. Thus we expect that higher resolution X-ray observations will show occasional bright, compact components which will not persist many years (*e.g.* Biretta et al. (1998) find optical features with these characteristics). If the December 1997 increase in knot A is real, it could represent emission from such a feature. AXAF observations have been proposed to obtain 8 monthly exposures with the High Resolution Camera.

References

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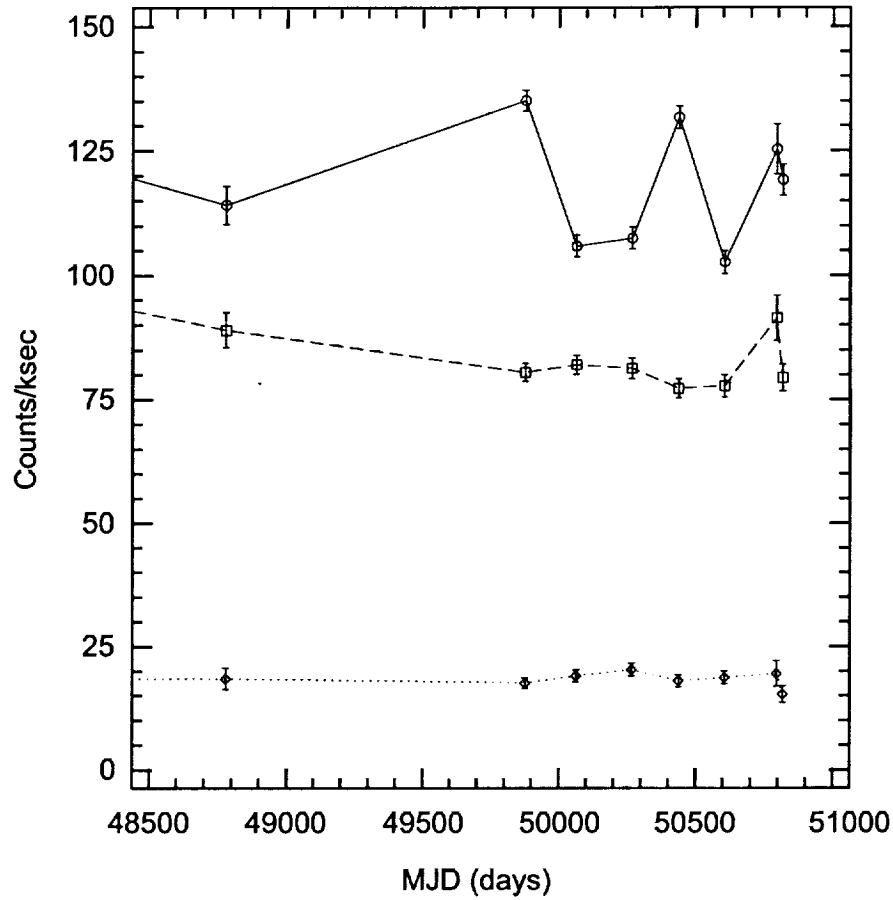
Fig. 2. The net count rates for the core, knot A, and a control region. The solid line is for the core, the dashed line is for knot A, and the control circle values are connected with a dotted line. Note that the control region is the net counts in a circle 45″ SE of the reference point, with the background from the frame. Therefore all control values are negative, but are plotted here as positive numbers. Thus the small apparent drop for the last measurement is actually in the opposite sense from those of the core and knot A. The lines running off the left side of the figure connect to the Einstein values (HBJ).